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LOW TEMPERATURE MECHANICAL PROPERTIES OF SEVERAL ALUMINUM ALLOYS AND THEIR WELDMENTS

By

P. C. Miller

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ABSTRACT

The mechanical properties of five aluminum alloys, 7079-T6 (forging stock), 5052-H32, 5086-H34, 5456-H343 and 2014-T6, were determined at temperatures from ambient to -450°F. The properties of as-welded butt joints were compared to those of the parent metal. The 5000 series aluminum alloys tested and 2014-T6 have excellent mechanical properties down to -450°F. Weldments of the 5000 series have high mechanical properties and are suitable for low temperature applications. Weldments of 2014-T6, although having high tensile and yield strength at low temperature, have low elongation values over the range from ambient to -450°F.

Alloy 7079-T6 is not recommended for critical applications at temperatures below -320°F, and caution should be exercised in the use of this alloy at temperatures below -200°F.

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ENGINEERING MATERIALS BRANCH
STRUCTURES & MECHANICS DIVISION

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SUMMARY

The mechanical properties of five aluminum alloys, 7079-T6 (forging stock), 5052-H32, 5086-H34, 5456-H343 and 2014-T6, were determined at temperatures from ambient to -450°F. The properties of as-welded butt joints were compared to those of the parent metal. The 5000 series aluminum alloys tested and 2014-T6 have excellent mechanical properties down to -450°F. Weldments of the 5000 series have high mechanical properties and are suitable for low temperature applications. Weldments of 2014-T6, although having high tensile and yield strength at low temperature, have low elongation values over the range from ambient to -450°F.

Alloy 7079-T6 is not recommended for critical applications at temperatures below -320°F, and caution should be exercised in the use of this alloy at temperatures below -200°F.

INTRODUCTION

An investigation was made to determine the mechanical properties of various aluminum alloys and weldments of the alloys in order to evaluate their usefulness for structural applications at cryogenic temperatures. Primary consideration was given to sheet materials for potential application in space vehicle skins, pressure vessels, and cryogenic fluid transfer ducts. Sheet alloys tested included 5052-H32, 5086-H34, 5456-H343 and 2014-T6. Alloy 7079-T6, used for high strength forgings in several applications, was also tested. The data reported represent that obtained to date on these specific alloys, and it should not be inferred that other alloys are not being considered for these applications.

The ratio of the tensile strength of a notched specimen to that of an unnotched specimen is considered to be an important criterion for the performance of a material in high stress structural applications. A high ratio indicates that a metal is tough and is resistant to fatigue failure or to sudden crack propagation under high stress. In this report, data are reported for notched-unnotched tensile ratios obtained with specimens having stress concentration factors intermediate between those of other recent investigators[1,2]. The criterion of "fracture toughness" is a subject of much current interest. The data presented in this report indicate the apparent wide difference in the various alloys in this respect.

The data also lend further proof that the mechanical properties of most of the alloys do not change linearly with respect to temperature and that it is very unwise to extrapolate such data.

EQUIPMENT

At the temperature of liquid hydrogen, tensile specimens were tested with a hydraulically loaded 60,000 lb. tensile testing machine in conjunction with a low temperature tensile cryostat, which is shown in figures 1 and 2. The specimen and apparatus were pre-cooled to -320°F with liquid nitrogen, which was exhausted prior to final cool-down with liquid hydrogen.

Temperature was sensed by copper-constantan thermocouples and controlled by a controller-recorder which actuates a solenoid valve located between the dewar containing the liquid hydrogen and the test cryostat. At intermediate temperatures, in the range of +80 to -320°F, a double-walled cylindrical cannister with spray holes around the inner periphery was inserted into the cryostat, and liquid or gaseous nitrogen, depending upon the temperature range, was sprayed onto the test specimen. At -320°F, the specimens were pulled while submerged in liquid nitrogen. At -423°F, the specimens were tested while submerged in liquid hydrogen.

Tests were made also at liquid helium temperatures (-450°F). A duplicate apparatus to that used for the liquid hydrogen tests was used for the helium tests, with the exception that the elaborate safety precautions observed with the liquid hydrogen facility were not necessary. The liquid hydrogen test facility was located in a remote area, while the liquid helium tests were made within the main laboratory. Controls for the liquid hydrogen tensile testing machine and cryostat were located in a shelter located approximately 75 feet from the test apparatus. The hydrogen test facilities are shown in figure 3.

This equipment was satisfactory to the extent that all temperatures were accurately controlled within $\pm 5^{o}F$, and that the average quantity of liquid hydrogen consumed per test was less than 7 liters. The strain recorder system is actuated remotely by a microformer mechanism which is clamped on the specimen extensometer.

SPECIMEN PREPARATION

All welds were made by the automatic TIG welding process. Machine settings normally used for production welds were used. The welds were examined radiographically before test specimens were prepared from the weld panels.

Tensile specimens were machined with a reduced gage section, 2.50" long and 0.375" wide. Sheet thicknesses ranged from .062 to .090". All weld specimens were tested with the weld bead intact and with no subsequent post-weld heat treatment.

Notch tensile specimens were machined with a reduced gage section, 2.50" long and 0.50" wide. A 60^{o} V notch with root radius of 0.0015 $\pm$ .0005" was machined on the edges in the center so that the width of the specimen between notches was approximately 70% of the original gage width. The resultant stress concentration factor (K_t) is approximately 10 for all the notched tensile specimens (see appendix).

RESULTS AND DISCUSSION

Test specimens of aluminum alloy 7079 were obtained from a primary structural forging in the T6 condition. Mechanical properties, oriented in line with the forging flow pattern, were determined for the temperature range of $-450^{o}F$ to $+80^{o}F$. The tensile and yield strengths are consistently higher than those of the other aluminum alloys (see figures 4 and 5). Below $-200^{o}F$, the low ductility and toughness, as indicated by comparison with the other aluminum alloys, should cause critical control of its use in this temperature range (see figures 6, 7 and 8). The fact that both ductility and notch tensile values are significantly lower than the other aluminum alloys may indicate that the 7079 forging alloy may be susceptible to failure by shock or dynamic induced stresses at temperatures below $-200^{o}F$.

There is a significant increase in ductility in aluminum alloys 5052 and 5086 from $-200^{o}F$ to $-320^{o}F$. An apparent transition occurs on decreasing the temperature to $-423^{o}F$, then again from -423 to $-450^{o}F$, where the degree of ductility in the longitudinal direction is still over 100% above that at room temperature (see figure 7). There is, however, an apparent loss of nearly 30 percent of the notch strength (see figure 8). Aluminum alloy 2014-T6 appeared to have good toughness qualities over the complete temperature range to -450°F and higher tensile and yield strength than 5456-H343, 5086-H34, and 5052-H32 (see figures 4, 5 and 8).

Weldments of the alloys tested did not have strength values and ductility in the same ratios as the parent metals. The very low ductility of 2014 weldments precludes the use of this alloy in areas wherein the elastic range cannot be predicted or controlled. The elongation of the transverse welded specimens was only about 2% maximum, as compared to 11% for the 2014 base alloy. The mechanical properties of the weldments of the aluminum alloys 2014, 5456, 5086 and 5052 are compared in figures 9 through 11.

The notched-unnotched tensile strength ratios, figure 8, show that 2014-T6 has superior notch toughness at temperatures below -320°F. This is not necessarily true for weld joints in 2014; however, it is considered that proper design parameters would eliminate excessive stresses in the weld joint. Notch strength for 5456-H343 was found to be unexpectedly low for the stress concentration factor used (K_t=10). Christian, etal, Convair Astronautics, obtained similar results with a larger notch radius than was used in these experiments. It appears, however, that other investigators have used smaller notch radii (K_t=20) and the relative ranking of 2014-T6 and 5456-H343 is much closer, or may even be reversed, according to the trend. This "notch toughness" factor has not been investigated thoroughly, and further tests will be made to clarify the ranking of these alloys with respect to crack propagation.

CONCLUSION

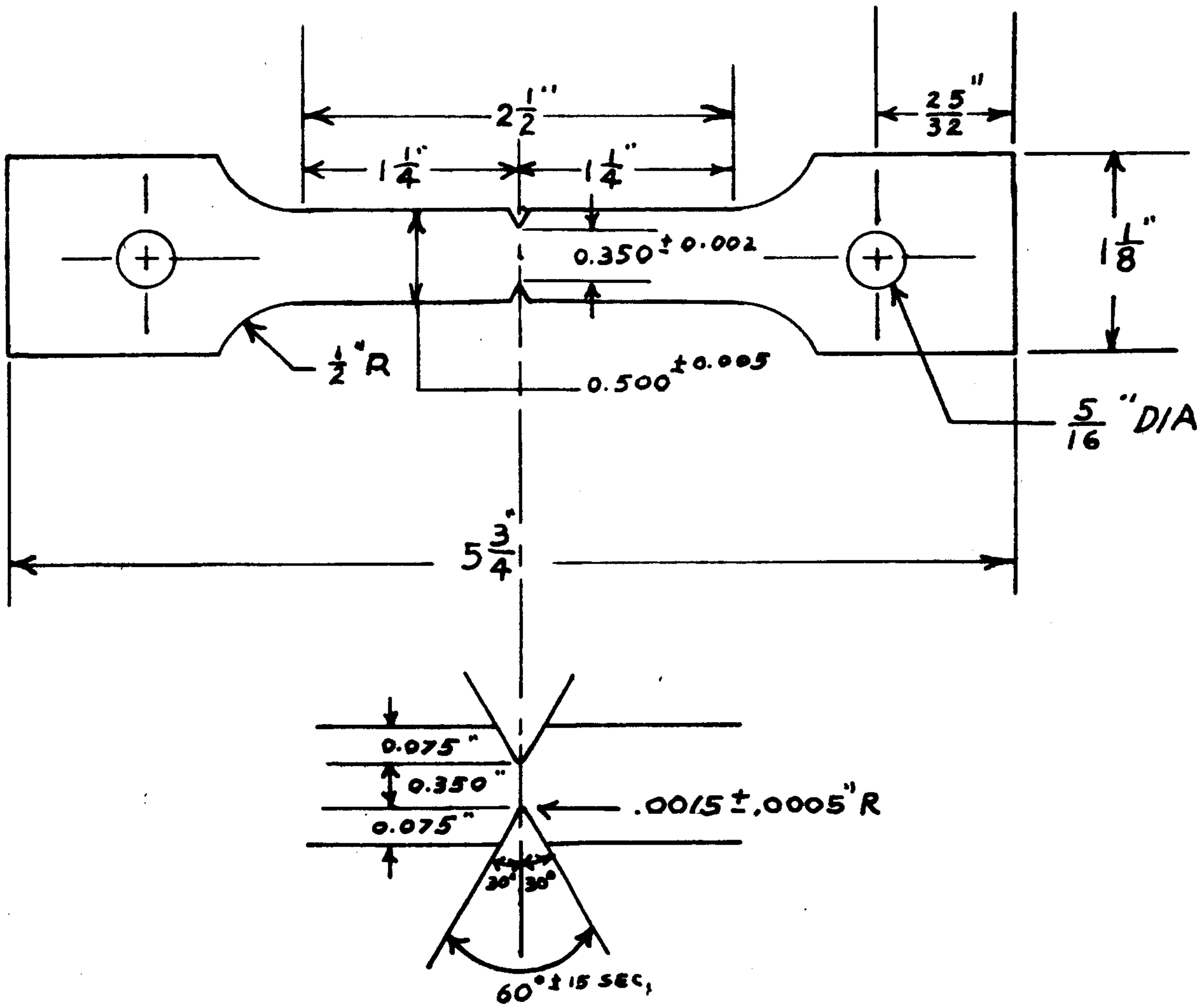
All of the 5000 series aluminum alloys tested and 2014-T6 were shown to have excellent mechanical properties down to -450°F. Weldments of the 5000 series have excellent mechanical properties and are suitable for low temperature applications. Weldments of 2014-T6, although having high tensile and yield strengths at low temperature, have very low elongation values over the range from ambient to -450°F. This alloy can be used for cryogenic applications provided this factor is considered in design of the structure.

Alloy 2014-T6 has a better notched-unnotched tensile strength ratio at -423°F than the 5000 series alloys. The difference in notched-unnotched ratio of 2014-T6 and 5052-H32 is negligible at -320°F; however, 5456-H343 is considerably lower at -320°F for the stress concentration parameters tested.

The percentage elongation of alloy 7079-T6 is very low at -320°F, and this alloy is not recommended for critical applications at lower temperatures. Caution should be exercised in the use of this alloy at temperatures below -200°F since both elongation and notch tensile strength decrease rapidly at temperatures below this level.

APPENDIX

NOTCH TENSILE SPECIMEN



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1. J. L. Christian, A. Hurlich, Mechanical Properties of Aluminum Alloys at Cryogenic Temperatures, Convair Astronautics Report MRG-190, December 1960.

2. M. P. Hanson, G. W. Stickley, H. T. Richards, Sharp-Notch Behavior of Some High-Strength Sheet Aluminum Alloys and Welded Joints at 75, -320, and -423 F, Special Technical Publication No. 287, ASTM 1960.

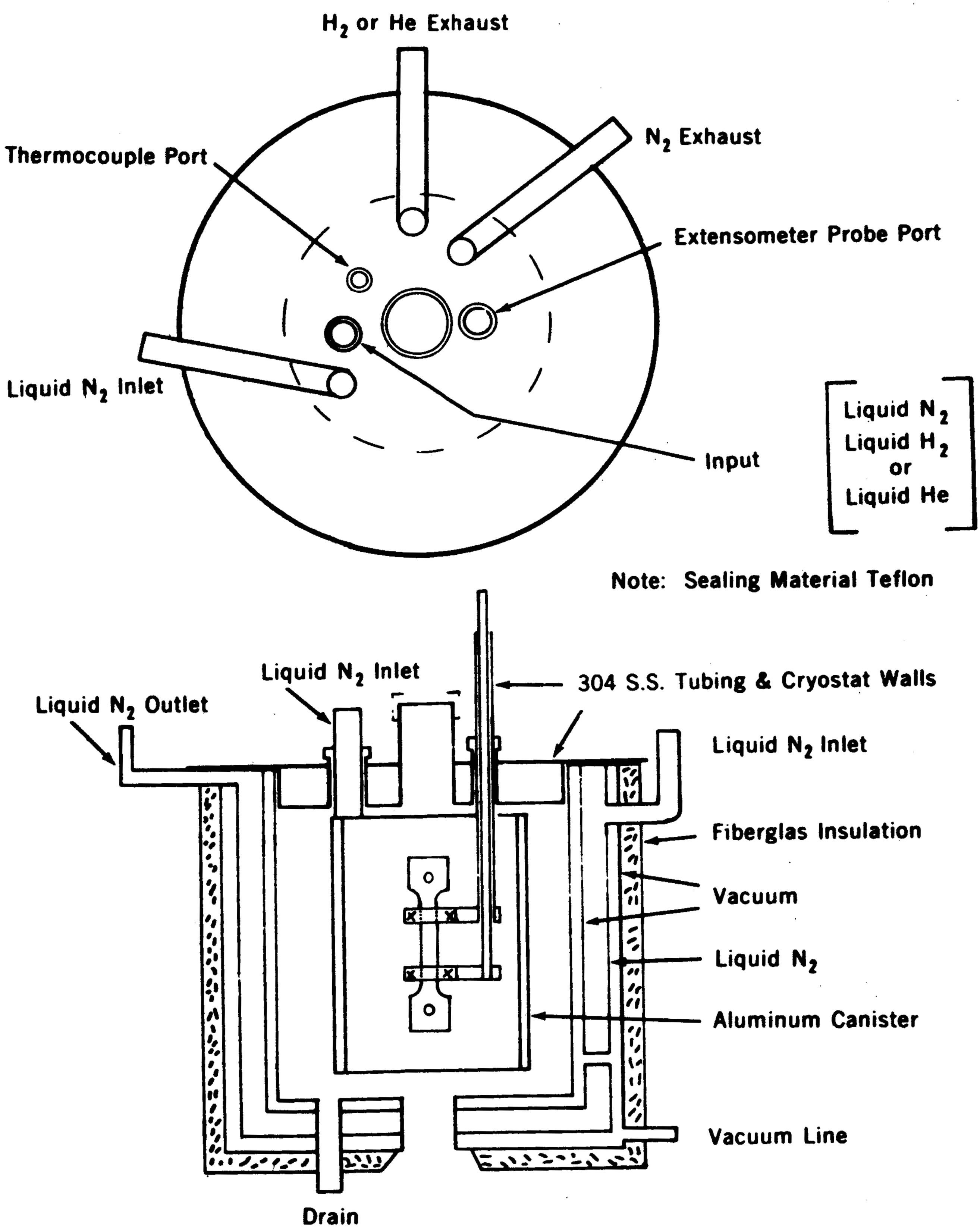

FIG. 1 DIAGRAM OF TENSILE CRYOSTAT AND EXTENSOMETER

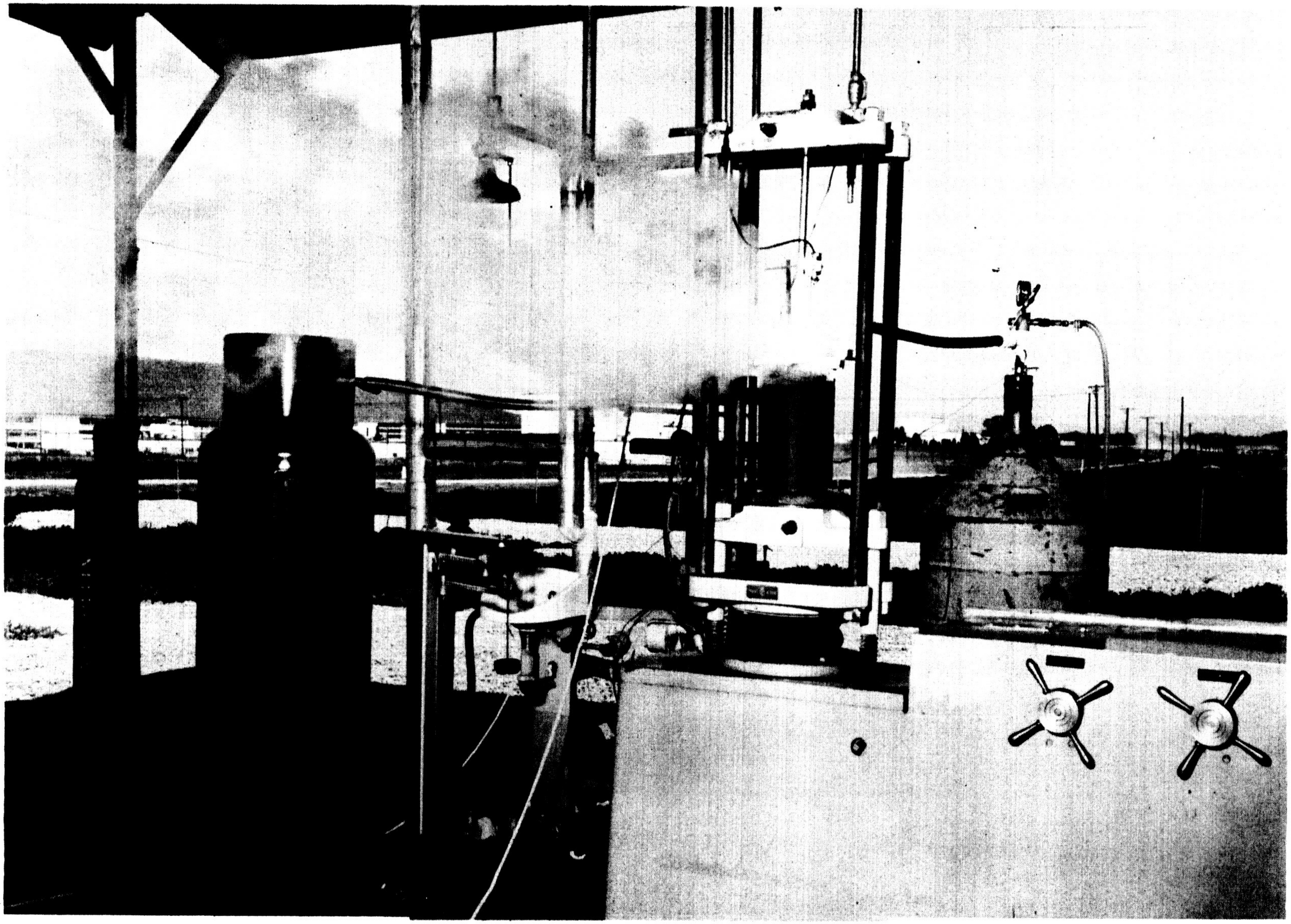

Fig. 2 Hydrogen Test in Operation

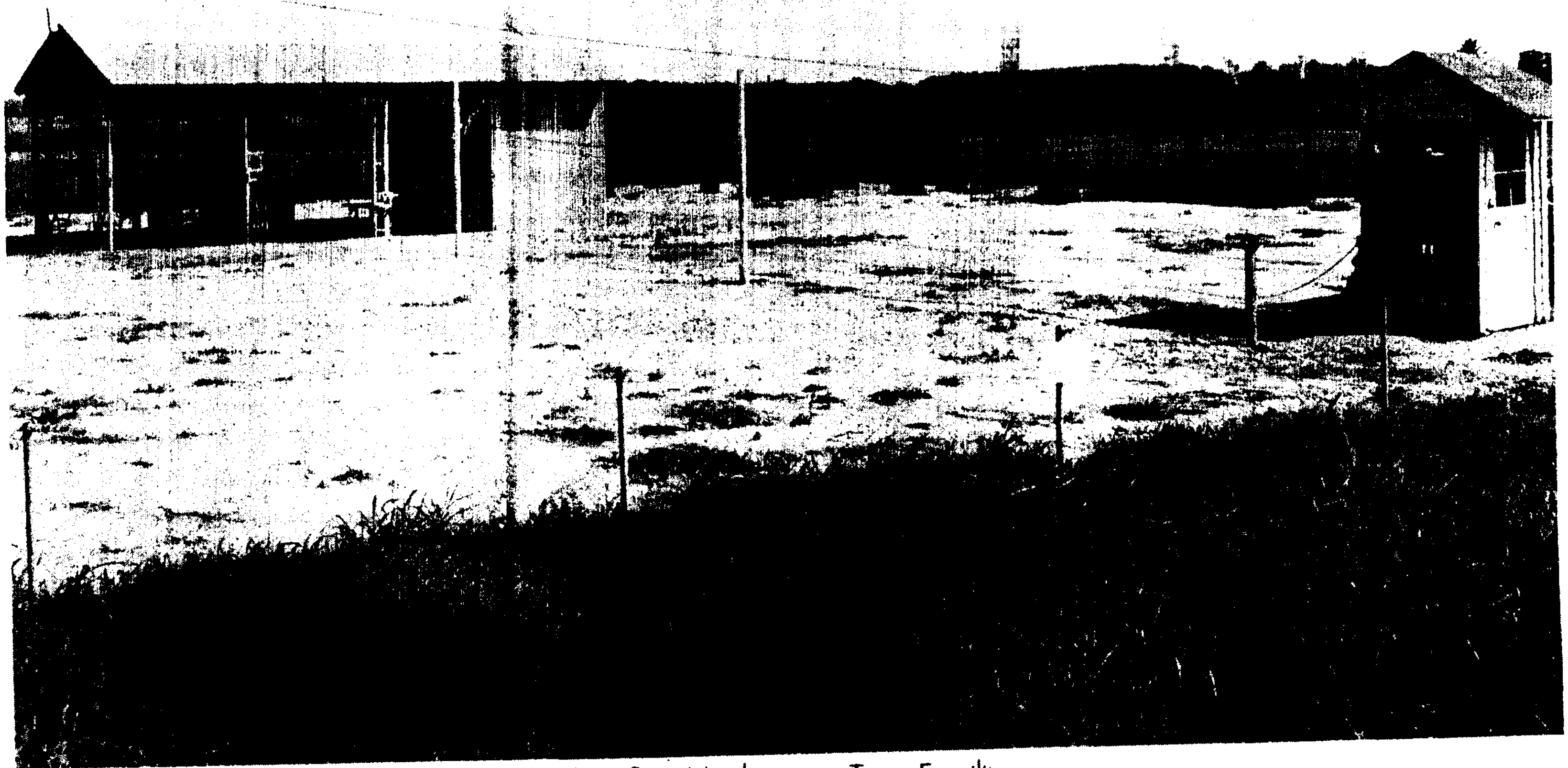

Fig. 3 Hydrogen Test Facility

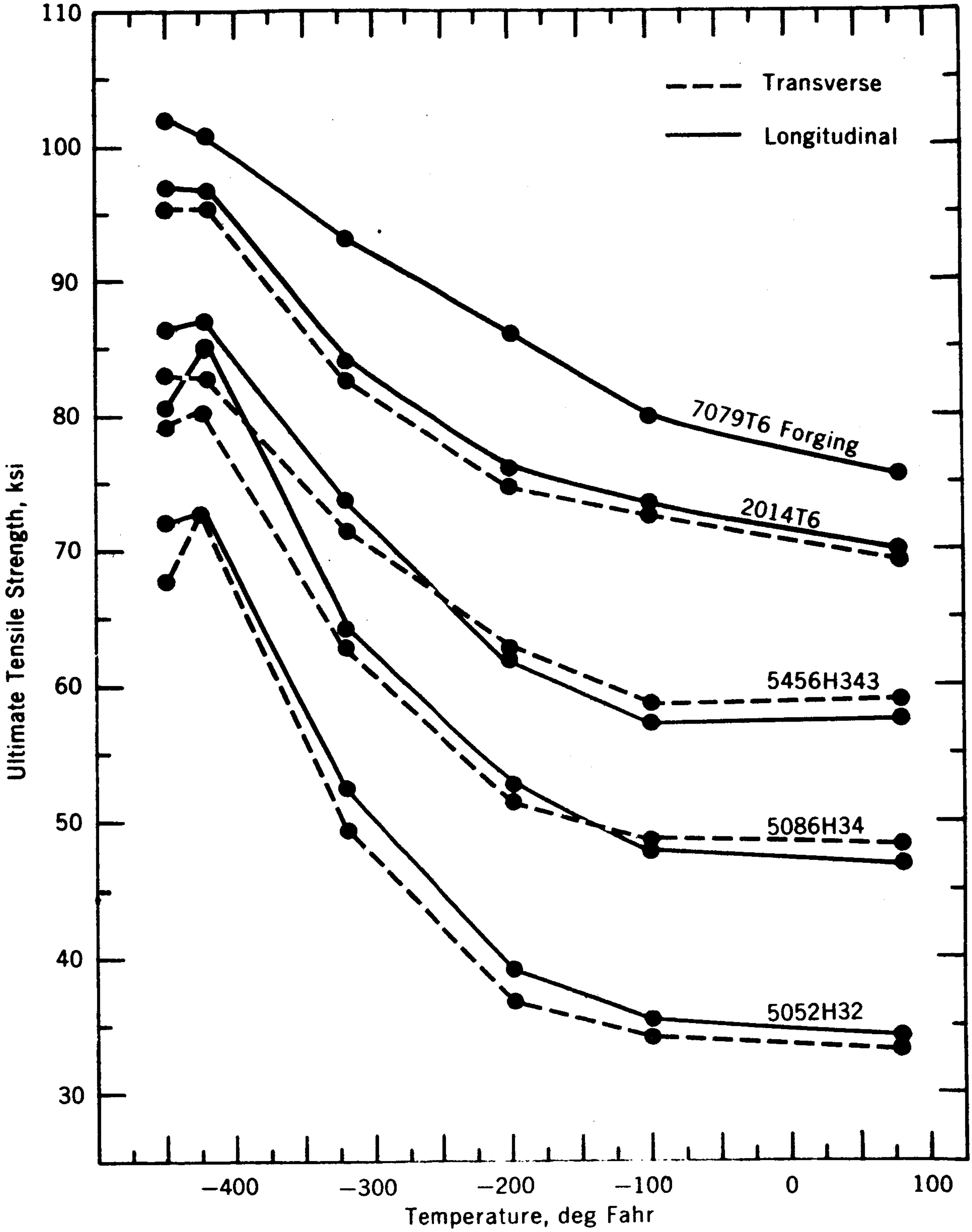

FIG. 4 TENSILE STRENGTH OF VARIOUS ALUMINUM ALLOYS, +80°F TO −450°F

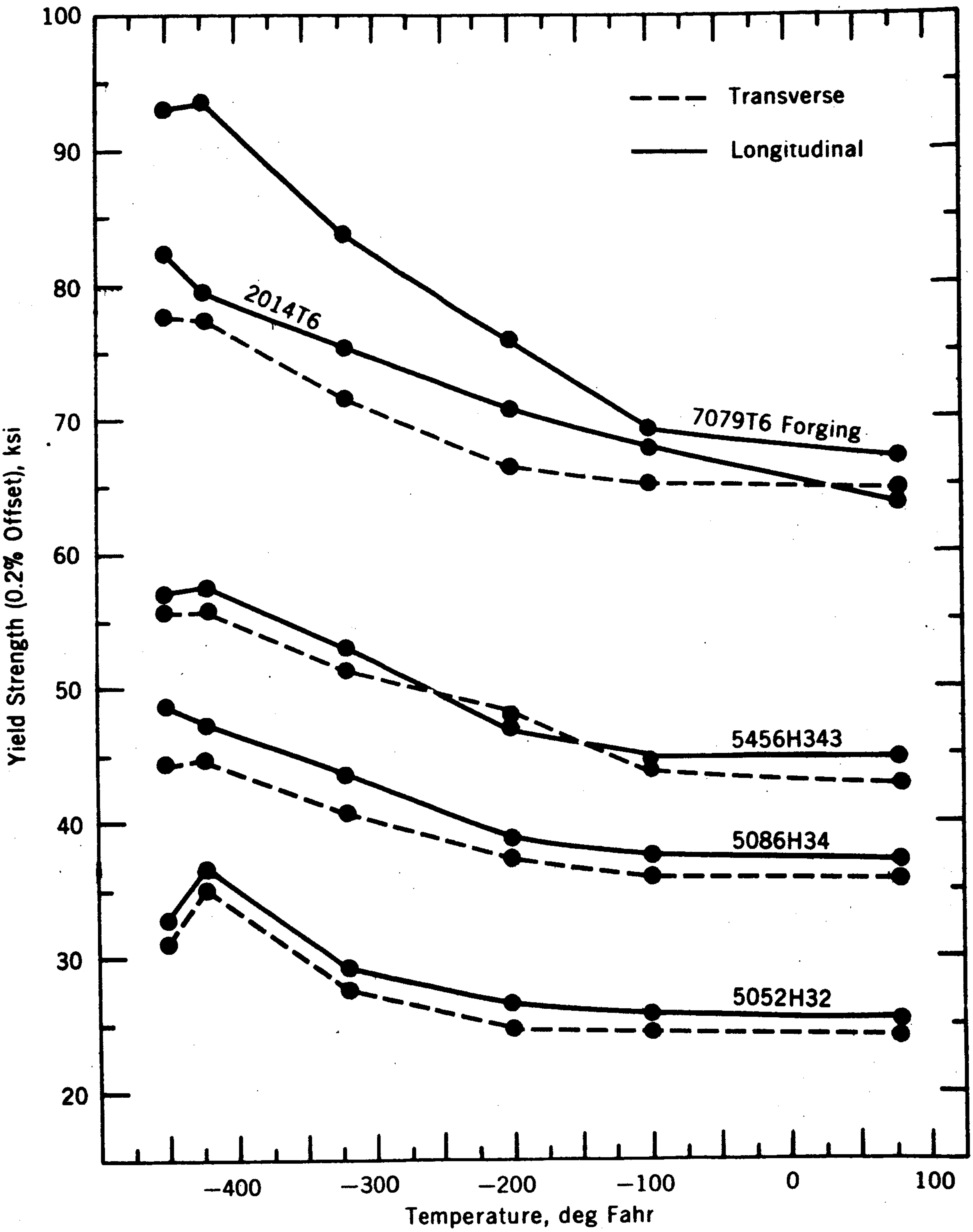

FIG. 5 YIELD STRENGTH OF VARIOUS ALUMINUM ALLOYS, +80°F TO −450°F

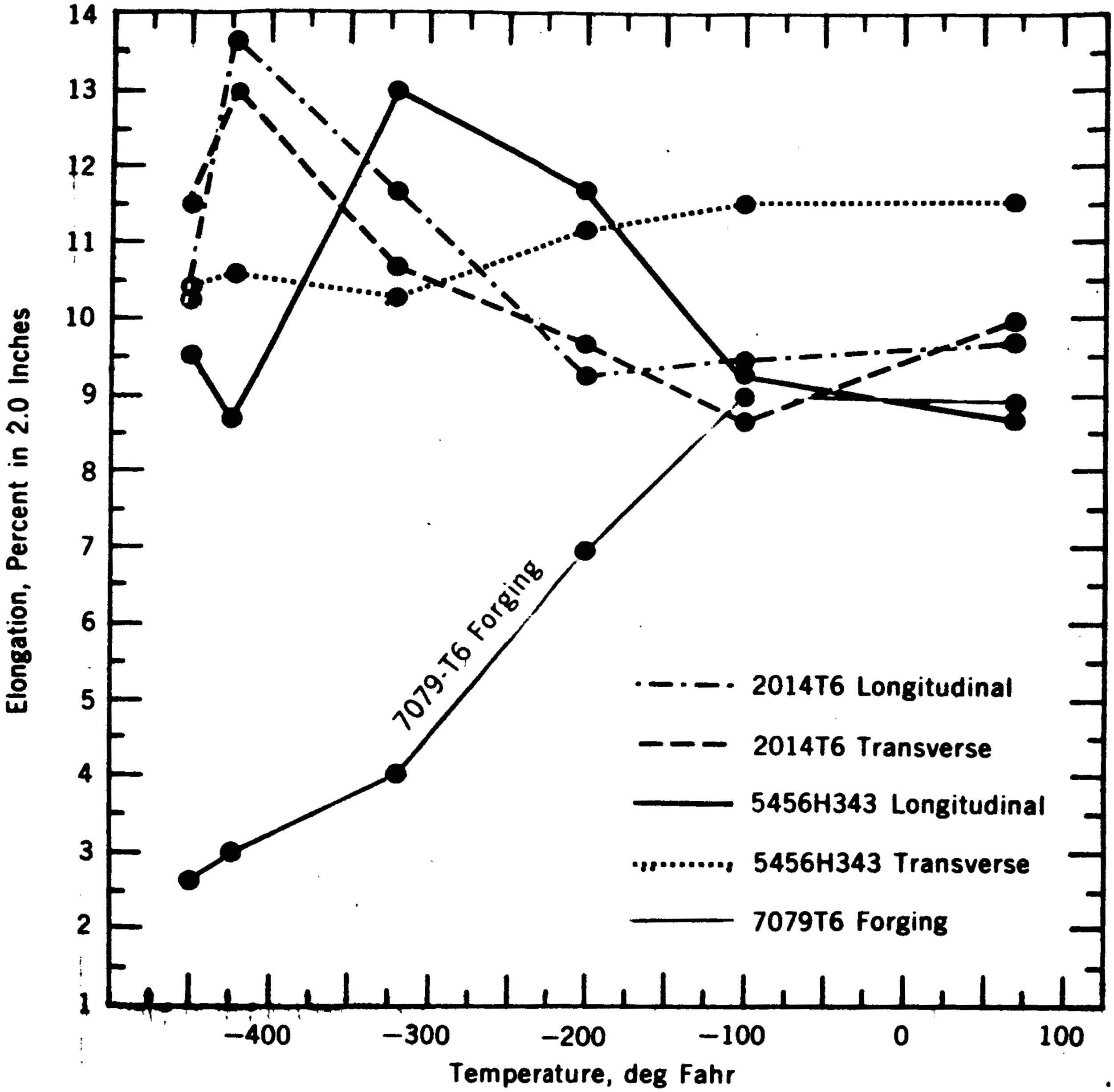

FIG. 6 ELONGATION OF VARIOUS ALUMINUM ALLOYS, +80°F TO −450°F

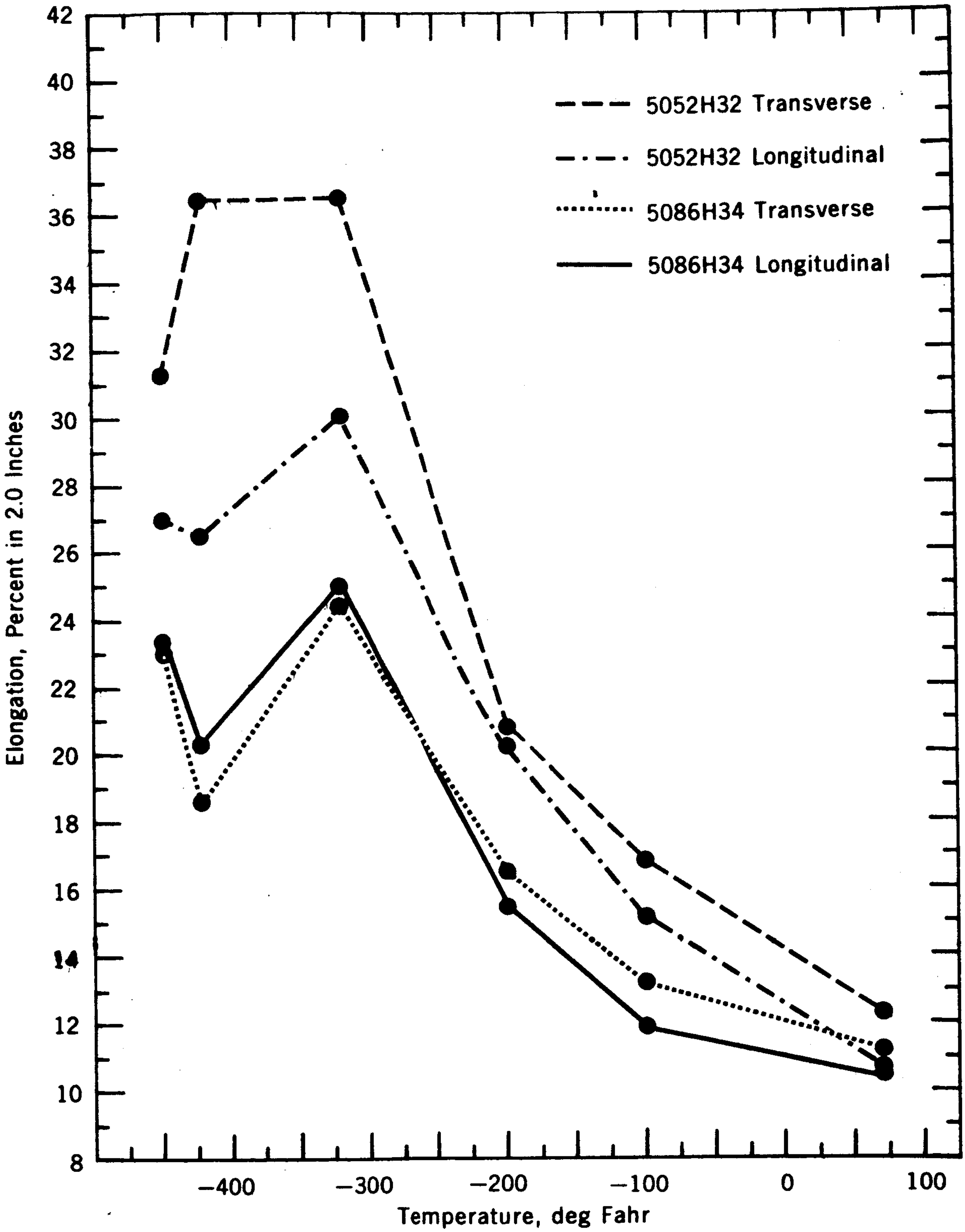

FIG. 7 ELONGATION OF VARIOUS ALUMINUM ALLOYS, +80°F TO −450°F

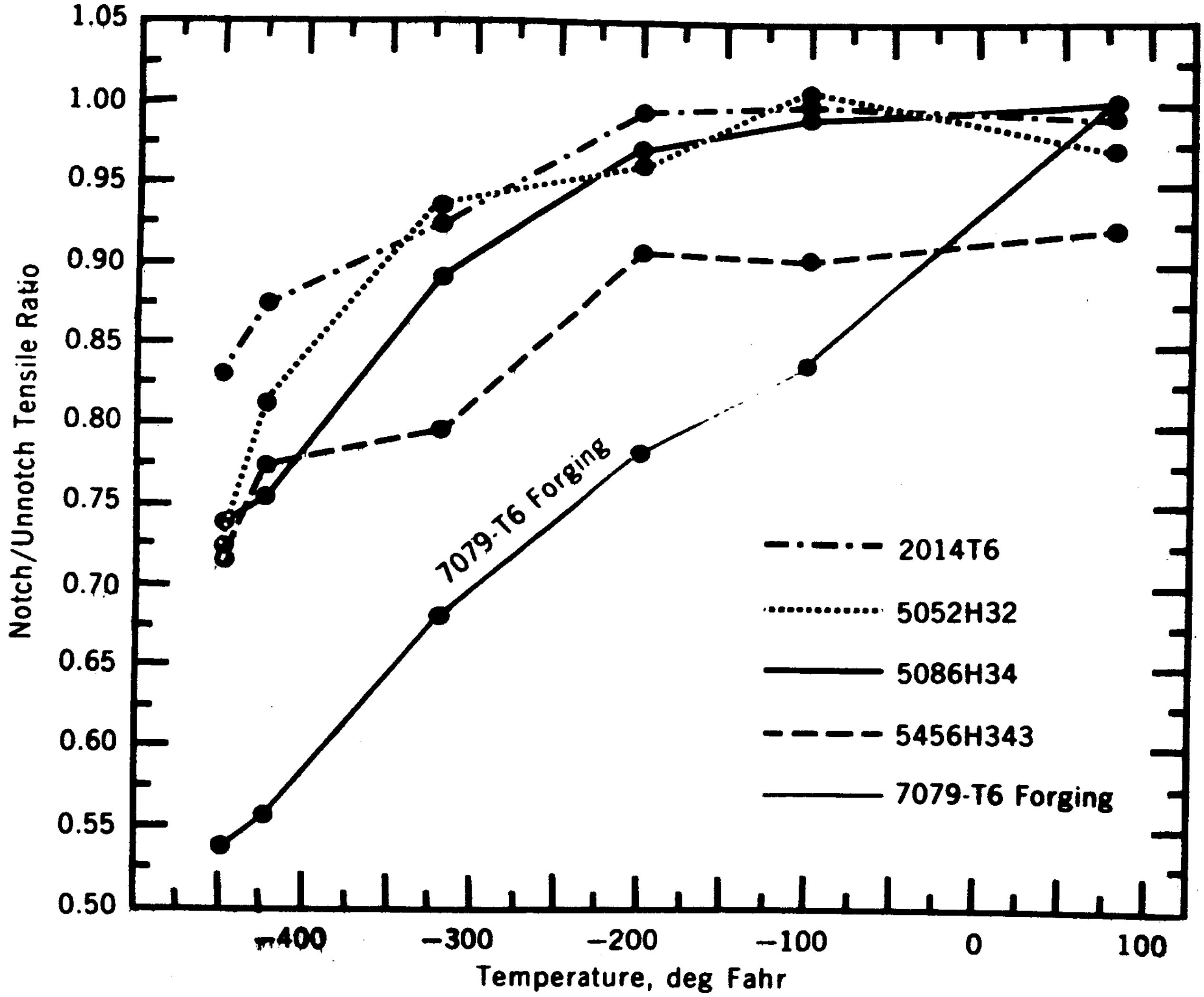

FIG. 8 NOTCH/UNNOTCH TENSILE RATIO, WROUGHT ALUMINUM ALLOYS, +80°F TO −450°F

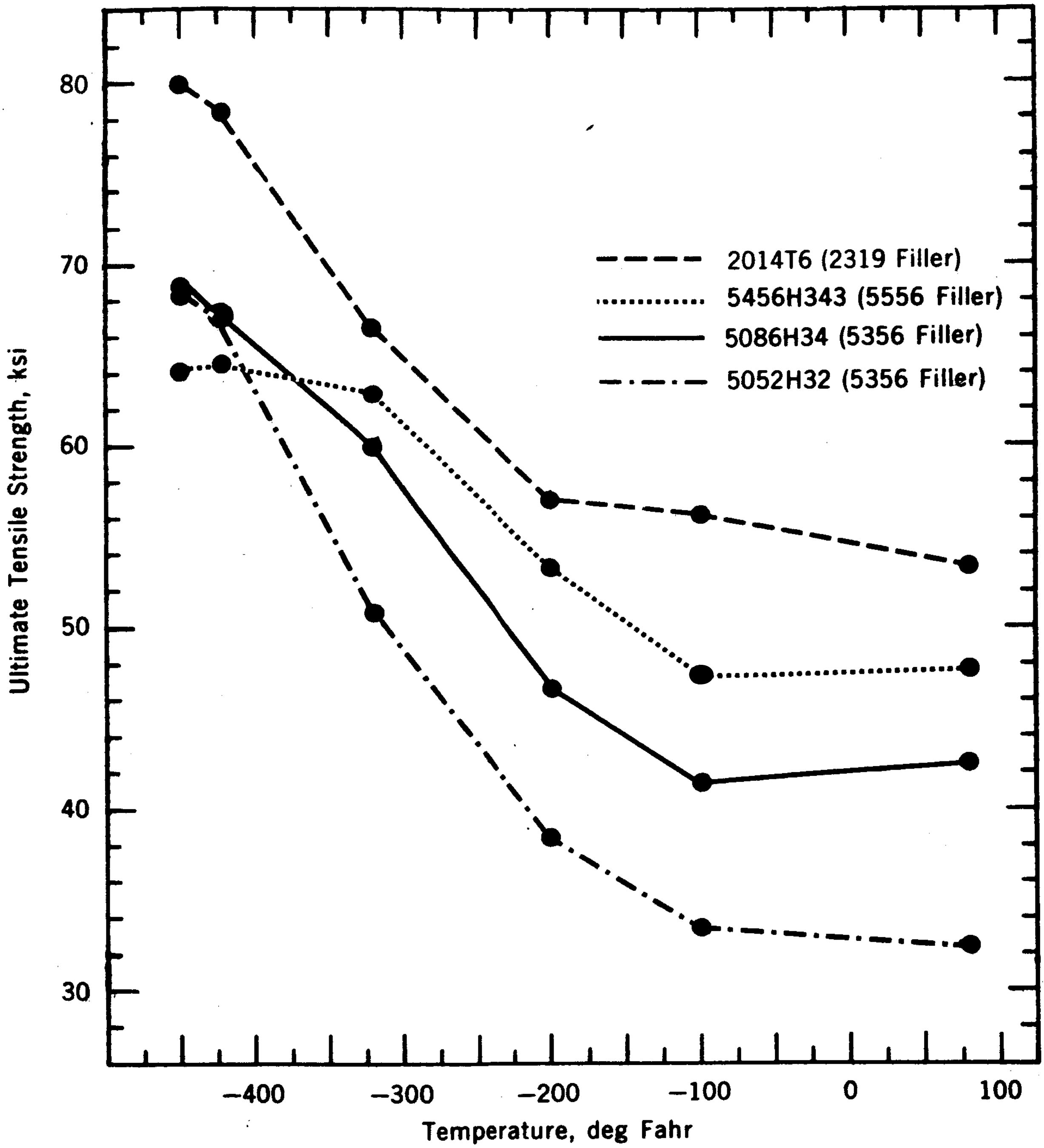

FIG. 9 TENSILE STRENGTH, TRANSVERSE WELDMENTS OF ALUMINUM ALLOYS, SHEET, +80°F TO −450°F

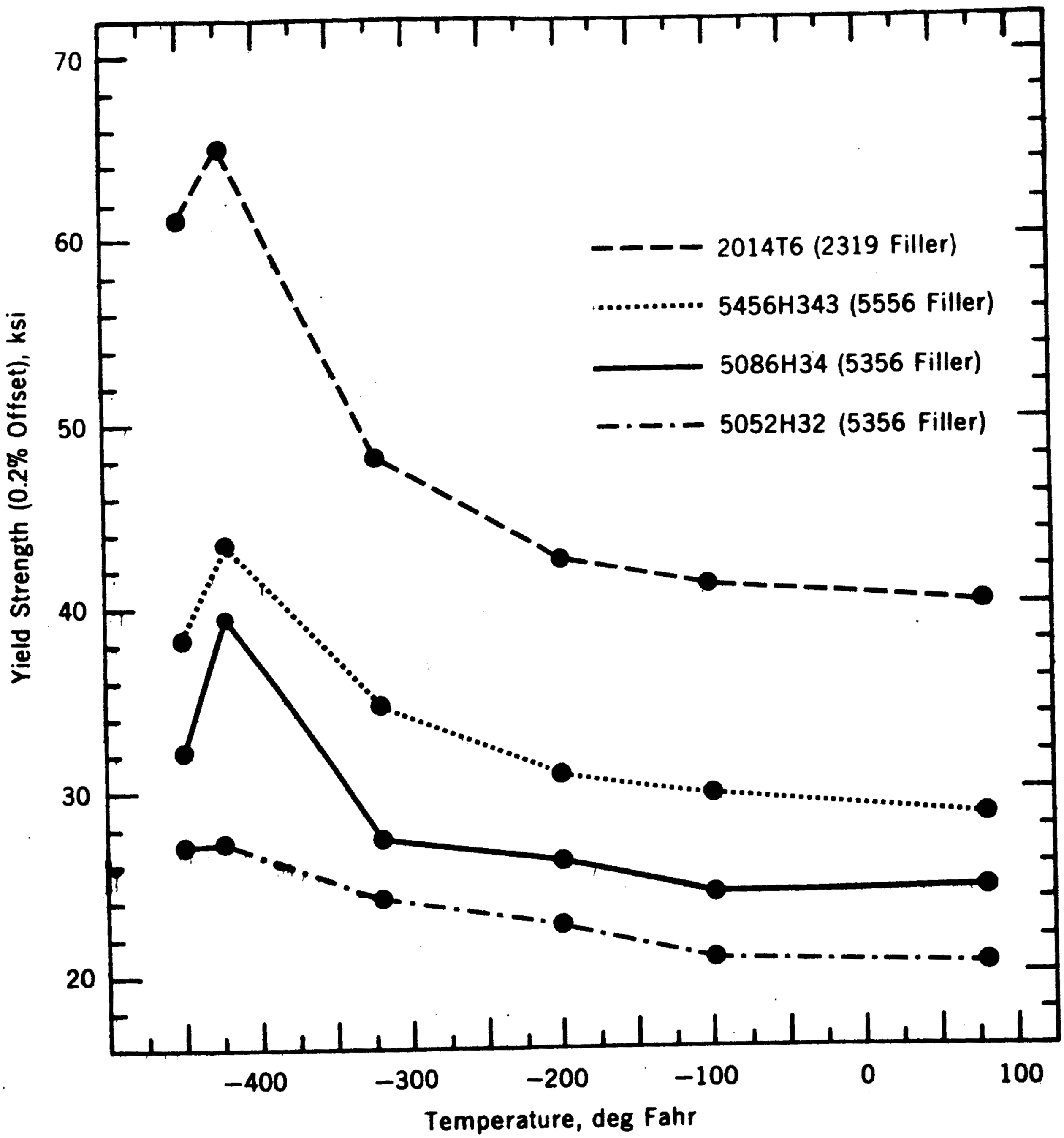

FIG. 10 YIELD STRENGTH, TRANSVERSE WELDMENTS OF ALUMINUM ALLOYS, SHEET, +80°F TO −450°F

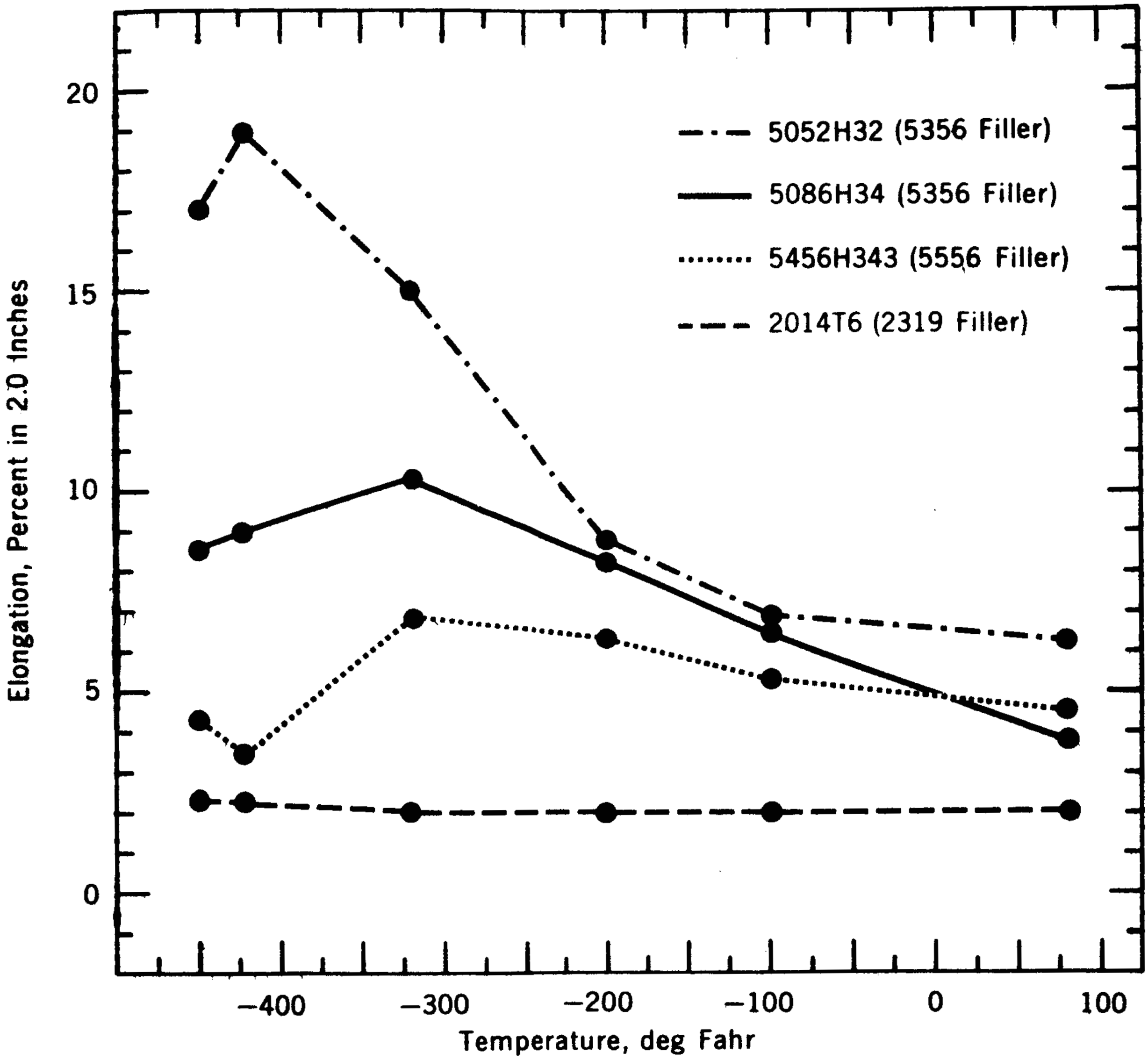

FIG. 11 ELONGATION, TRANSVERSE WELDMENTS OF ALUMINUM ALLOYS, SHEET, +80°F TO −450°F

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